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A Modular Signal Processing Architecture to Mitigate Obsolescence in Airborne Systems

Markus Rothmaier
EADS Deutschland GmbH
Defence Electronics + Telecommunication
Airborne Systems
Wörthstraße 85
89077 Ulm
Germany
Tel: (49) 731 392 5227
Fax: (49) 731 392 4947
Email: markus.rothmaier@vs.dasa.de

Summary

After providing an introduction to the obsolescence problem, this paper explains how the topic is handled to dated, using an airborne radar system development as an example. In this, the supplier primarily reacts on obsolete components with post design measures. In contrast to this a pro-active approach is suggested that starts with defining an architecture that eases the substitution of obsolete components and allows upgrades without involving major redesigns. This includes the need to safeguard the effort spend for developing and qualifying application software.
The article presents a modular structured signal processing architecture that employs COTS modules and standards. It discusses the ability of such an architecture to cope with the obsolescence problem by separating interfaces from processing units and applying COTS interface standards. Means of the designer are examined that allow to proactively design a processor that is likely to survive hardware and software component changes at minimum cost. Forming standard building blocks that encapsulate processing functions is presented as an approach that will considerably reduce the involved risk.

Situation Today

The Obsolescence Problem

Development and supply of todays digital components has been adapted to the needs of the commercial markets, especially to support mobile communication and consumer products, as these by far outnumber the required components in the defence industry. This affects both, the components availability and their capabilities.
The life cycle of telecommunication and consumer products, e.g. mobile telephones, ranges between 2 to 5 years, whereas the defence products show a life cycle time in the order of 20 years and more. Suppliers for key components like memory and microprocessors have life cycle times of about 2 to 4 years, adopted to their main customers. As a result, a defence product has to cope with the same component becoming obsolete in the order of about 5 to 10 times during the equipment life time. This will most likely start at the beginning of the product life cycle, i.e. during the definition and development phases.

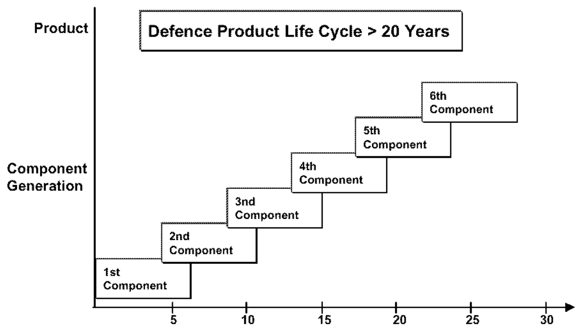

Figure 1: Equipment and Component Life Cycle

The virtue of such frequent component upgrades is a permanent enhancement in performance and functionality of components that includes low power consumption as the supply voltage levels drop. In the past, military applications drove the performance and functional specification of digital components. This has changed, as the telecommunication and consumer markets produce nowadays complex products as well, with a need for high performance, low cost components.
The major differences are the harsh environmental conditions a component has to sustain in a defence product as well as the product reliability it has to support.
For airborne applications in an military fighter aircraft, the most severe environmental conditions include:

- Wide temperature range of both the ambient and the cooling air (if any).
- Humidity, especially when high temperature and pressure gradients are to be faced.
- Mechanical shock and vibrations

MIL standard components have been able to cope with these conditions, as they were designed for them.

Paper presented at the RTO SCI Symposium on "Strategies to Mitigate Obsolescence in Defense Systems Using Commercial Components", held in Budapest, Hungary, 23-25 October 2000, and published in RTO MP-072.

However, due to the rapidly diminishing share of military applications on the semiconductor market, MIL standard components are vanishing.

Industrial, and especially commercial grade components specifications do however not consider these environmental conditions. As they are designed for cheap mass production, their design includes:

Plastic encapsulated modules (PEM)

Low voltage supply

Since the life cycle of commercial products is much shorter compared to military avionics equipment, the required product reliability can be lower. In military applications a primary failure rate of only a few occasions per 1000 operating hours can be accepted. Equipment that is involved in flight safety has to fulfil even more stringent reliability requirements.

Whether the predicted reliability of equipment applying industrial / commercial components suffices depends very much on the prediction method. MIL Handbook 217 is generally considered to be too pessimistic compared to other methods.

PEMs may not only reduce the equipment reliability in severe environmental conditions, but also require careful storage to avoid penetrating humidity and pin corrosion. The same level of care should be taken during production to avoid e.g. contact with perspiration.

Figure 2 summarises the facets of the obsolescence problem as outlined above. Component suitability may be tackled by design methods, of which some are outlined later in this paper. Regardless of those, the problem of component availability and high frequency of upgrades remains and will most likely cause a number of serious impacts on any military development project:

Production of military products will be more difficult as the list of components will change frequently during series production.

It becomes increasingly difficult to procure spare components.

Permanent and frequent design activities are necessary during series production. Obsolete components will have to be faced already during the definition and development phases.

An ever increasing gap between the technology used in commercial products and the technology applied in military applications.

The inevitable re-designs of processing H/W require the transfer of the highly expensive application S/W on new processing platforms.

The error in programme cost estimates will increase as the effort for future obsolescence removal activities is difficult to estimate, but a significant factor.

All of the above will increase the product cost over the product life time. However, with methods, which are described in the following sections, these costs could be minimised (except for the last bullet above, which will not be covered in this paper).

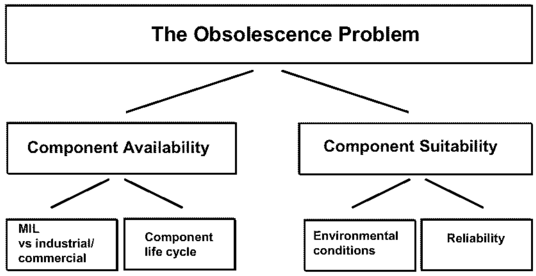

Figure 2: Obsolescence Problem Tree

Today's Strategy

Avionics systems coming today to series production are based on developments in the 90ties. In the digital and especially in the processing area they were driven by thoughts as

Minimise the number of different components and therefore maximise the amount of equal components for series production

Use of "Common Standard Boards"

Increase production quantity of equal boards with equal processes

If required, support the processing power by dedicated ASIC's, e. g. as hardware accelerators for mathematical operations

The cycles from development to production was planned as phased approach with

Development Phase

Qualification Phase (which may be part of the former phase)

Production Investment Phase to prepare the necessary facilities and tooling for series production

Series Phase

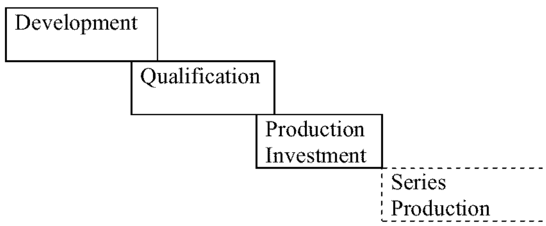

Figure 3: Equipment Phases vs. Time

Keeping in mind the development duration for military avionics products of approximately 8 to 10 years and the progress made in technology between, the supplier is faced with the challenge that the just developed and qualified product is not manufacturable. This is extremely valid in the processor and ASIC area were, for example, the physical structures had shrinked from 1.5 µm down to 0.35 µm and below in the meantime. Therefore, most of the ASICs became obsolete.

It had become necessary to expand the Production Investment Phase by an additional development phase to mitigate known obsolescence at time of starting the Production Investment activities. This results also in an

additional (and at least partly) re- qualification of the modified equipment.

Unfortunately, the injection of a re- design cycle mitigates the obsolescence problem only at the moment, but not in medium and long term aspects. With the ongoing strong decrease in the availability of military components forced by

- disappearing of key vendors from the military market (e.g. LSI Logic),
- company sell offs in the ASIC business (e.g. GEC Plessey, TEMIC),
- change in base technologies (e.g. ECL supersedes CMOS, 3.x V replaces 5.0 V),

the obsolescence problem overhauled the re- design and is back again. This situation is known in the mass market but indeed new for military developments.

Therefore, to come to a production phase the following options are possible and request a careful component by component observation

- Re-Design
  If a certain amount of components is obsolete or marked to become obsolete in shorter time, a re-design is necessary to mitigate the obsolescence risk for the start phase of Series Production.
- Re-Specification
  Components specified according to a very high quality level should be observed if a lower qualification level could be accepted and if the component is available at this level (e.g. QPL component replaced by MIL 883 type).
- LastTimeBuy
  Considering the time consumed for a re- design / re-spin of complex key components (e. g. ASICs) it should be necessary to perform a Last Time Buy. This possibility should also be selected if a component becomes obsolete after start of re- design and could not be included in this cycle.

Any of the above discussed possibilities must be chosen after careful observation regarding

- Schedule
- Risk
- Impending re- qualification

Experience in an avionics project shows that after finalisation of the development phase

- 75 % of the components are still active
- 11 % of the components require a re- specification
- 1 % of the components require a re- design
- 13 % of the components require Last Time Buy

The Last Time Buy number in this example is quite high as the design key elements are ASIC's which become obsolete by reasons discussed above.

In any case, a sophisticated obsolescence management has to be established to observe the relevant component market and gain early recognition of upcoming component obsolescence. As efficient as the established obsolescence process in each company or in consortia is, it mainly suffers from

- Availability of Last Time Buy Warnings
  Not all component vendors issue early warnings for upcoming obsolescence. Today's practice shows that components are becoming obsolete without public notice. The problem is recognised by the user at time of placing an additional / new order.
- Number of avionics systems to be built is not fixed.
  Forced by the existing lack of funding at the military purchasers the total number of items to be built is not fixed at production start. This means that the suppliers keep the risk in definition of the number of systems to be built as well as for the required logistic spares (item and component spares)
- Financial penalties
  Last time buy of components bind a not small amount of money in a very early phase of Series Production with all resulting penalties for the financial backer. Note that not seldom the equipment manufacturer has to take the burden to finance this stock.
- Technical penalties
  Long time storage of components may influence the processability in terms of e. g. solderability. Whilst in the early 90ties only logistic stock components had to be prepared for long term storage and stored in special stocks (protective gas environment) nowadays production and spare components have to be protected. This additional effort enhances also the overall costs.

Applying above principles to an existing avionics project which was developed in the 90ties and comes today to first Series Production deliveries, the financial effort could be characterised by

- Development Phase 100 %
- Obsolescence driven re- designs: 7 % of the Development Phase during Production Investment Phase
- Last Time Buys
  a) Not re- designed key components: 5 % of the Development Phase
  b) Upcoming obsolescence after Re- designs: 1 % of the Development Phase

The experience from the example project could be summarized by

- Obsolescence Management and mitigation must start with the Development Phase
- Last Time Buy of (at least) components is opportune
- A re- design cycle between Development / Qualification and Series Production forced by obsolescence is necessary

Revised Approach

All of the current methods to tackle the obsolescence problem as outline above, start once the equipment design is finished and components become unavailable. During the 80's and early 90's the electronic component selection process in military airborne applications was mainly driven by the requirement to use MIL standard components, preferably with a second source.

Architectural and design decisions were not influenced by the risk of diminishing manufacturing sources (DMS).
As the obsolescence problem starts to become the primary reason for re-designs and additional cost of ownership, the obsolescence issue needs to become an integral part of the equipment definition and development phase.
It is estimated, that about 70 to 80 percent of the overall product costs are committed during the first 20 percent of the development cycle. Hence, guidelines are required, that pro-actively address the DMS problem at the start of an equipment life cycle, when an equipment architecture is defined.
An architecture needs to be established, that minimises the re-design effort and duration once a component becomes obsolete. For this, an 'open architecture' is preferred, that supports established standards. Obviously, such an approach has the potential, to support future upgrades driven by the desire for performance and functional enhancements.
With the architecture being prepared for future obsolescence driven activities, the next step is to include the issue of DMS into the focus of the design activities of a new product. Use of commercial and industrial grade components, life cycle projection and careful environmental design are amongst the topics to be considered during the design process.
Both, architectural and design activities need to be embedded into a permanent obsolescence management process, that becomes part of the project management.

MSP2 - An Architecture Proposal

The Modular Signal Processor (MSP2) is being developed in a proprietary funded project that was started in 1998 at EADS, Airborne Systems in Ulm to build up a basis for a family of signal and data processors for military airborne applications. It is an evolution of the MSP system that was successfully applied in a number of military projects. MSP2 has now successfully passed the acceptance test phase.
A typical processor for a military airborne application consists of the following MSP2 parts:

- Signal Processing Module (SPM)
- Data Processing Module (DPM)
- General Purpose I/O
- Aircraft Interface
- Fibre Channel Network
- Optical Backplane

It is intended to be a processing platform that is scaleable in terms of form factor, processing power, and communication bandwidth. A typical MSP2 system is shown in Figure 4.

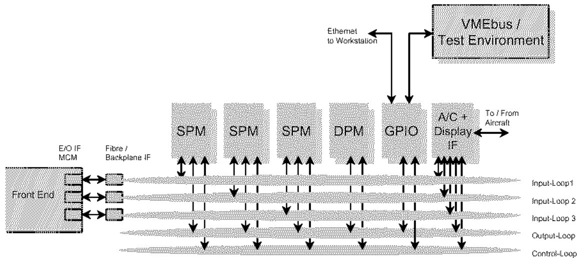

Figure 4: Typical MSP2 System

The interconnection between multiple Processing Modules (SPMs, DPMs, etc.) is achieved by linking the Fibre Channel Interfaces (FCIs) of several modules, either via discrete connections (coax cable or optical fibre) or via an optical backplane. These links are always implemented as loops. A typical system consists of several loops. The data exchange between different loops is done via the Routing capability on the Processing Modules.
A Processing Module (PM) consists of the following Building Blocks (see Figure 5):

- Processing Element (PE)
- Fibre Channel Interface (FCI)
- Module Support Unit (MSU)
- Routing Network

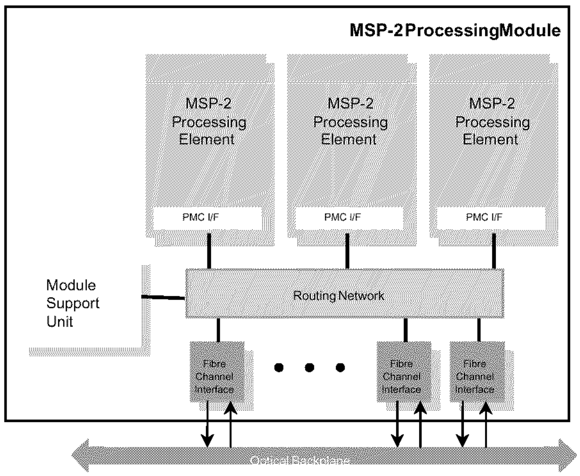

Figure 5: MSP 2 Module Architecture

The first implementation of a Processing Element are the Signal Processing Elements (SPEs) which are currently realised as PCI Mezzanine Card (PMC) modules. Hence the PM provides PMC slots for the mounting of the PEs. Off-the-shelf PMC modules may also be mounted on such a slot. Currently, the SPE is based on the Texas Instruments DSP TMS 320C6701 which provides a nominal throughput of 1 Gflop.
The Module Support Unit consists of a PowerQUICC Microprocessor, associated memories and a PCI-interface chip. The main functions of the MSU are: PM management including Built-In Test (BIT) and Fault Log, as well as the control of the intra-module data

transfer (between the PEs) and the inter-module data transfer (between PMs via the FCIs).
The Fibre Channel Interface provides the external interface to the PM. They are either connected to an optical backplane or to discrete connections such as coax cable or optical fibre. A first variant of the FCI has been produced as PMC module with discrete fibre connectors. Next generations will be an integrated part of the Processing Module.
The Routing Network provides the on-board interconnections between MSU, all PEs, and the FCIs. It consists of several PCI busses and PCI bridges.
The Optical Backplane, in conjunction with the optical tranceivers of the FCI, provides the board to board interconnection. A combination of free space and guided wave transmission is realised.
In order to achieve a modular design, the MSP2 architecture has been structured into Building Blocks that can be considered as the smallest entities of the MSP2. In fact, by varying the number of Building blocks and the number of modules, the MSP2 architecture is scalable and can be adapted to the needs of a specific project. Those Building Blocks are: Fibre Channel Interface, Module Support Unit, and Signal Processing Element. They all have a PCI bus interface in common. Other Building Blocks are to be added at a later stage, e.g. a Data Processing Element. Figure 6 depicts a family tree of the MSP2 architecture that show the modular design of it.

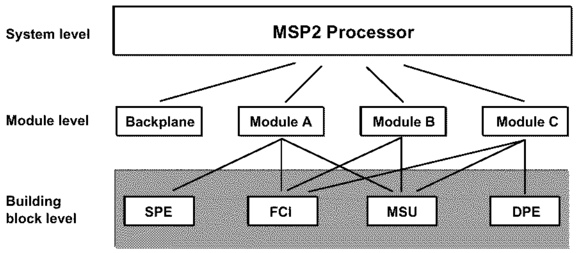

Figure 6: MSP2 Family Tree

Software for the MSP2 will be organised in different layer as shown in Figure 7, starting with the Board Support Package. This layer not only includes the necessary drivers but also the system management software that organises tasks like power up, system configuration, data transmissions, and build in test.
A COTS operating system forms the next layer, which will be separated from the application software by a ASAAC compliant APOS layer.

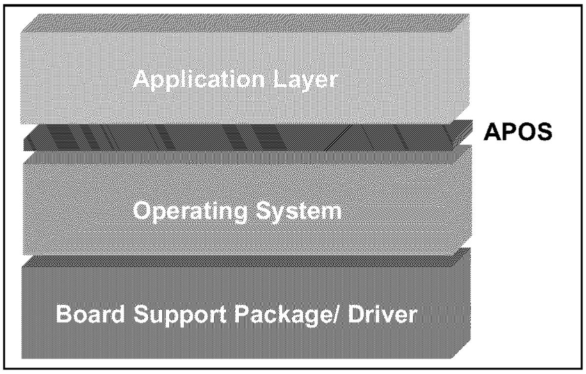

Figure 7: Software Layered Structure

Blueprints are used in order to map the application to the MSP-2 hardware. Blueprints present logical system descriptions using a standard format, thus providing a means for changing the system characteristics without having to change the application or operating system code. Blueprints are used for an application specific system design and for run-time system configuration purposes. In detail, Blueprints are broken down into the following three categories:

- Application Blueprints which formally describe an application's characteristic, e.g. its decomposition into processes, its internal states, its performance parameter, its related communication elements.
- Resource Blueprints which formally describe the logical representation of hardware resources.
- System Blueprints which formally describe system integration and configuration decisions for a specific implementation of an MSP-2 system. This includes mapping information by means of relations between applications and resources, e.g. system state transition tables, process scheduling tables, communication channel assignments

Architectural Features that mitigate Obsolescence

Modular Concept

Forming a modular structure as in the MSP2 architecture carries a number of advantages with respect to obsolescence.
The most obvious is the efficiency improvement during the development. Once a building block has been designed and tested, it can be copied by a community of users, i.e. the Module Designers, that do no longer have to repeat the same development and verification tasks. This will lead to a hardware design library which can grow and mature. This level of modularity is achieved by separating the operational functionality of a module from the actual hardware resources/design.
Once a component on a building block starts to decline on its life cycle, re-design activities unavoidably have to be started to ensure the continuing availability of the affected building block. However, in contrast to the past

approach, that caused a re-design effort in every instance the obsolete component was used, the modular approach allows to concentrate the effort on one building block, including test and qualification. Once the building block re-design is complete, it can be copied to every module that applies this building block, with only a moderate qualification effort on module level.
Applying a modular approach as for the MSP2 processor also reduces the number of different components used in the airborne equipment. This allows to concentrate the component selection process on a reduced variety of components and eases the obsolescence management process.

Standard Interfaces:

The MSP2 architecture is based on two interface standards. On the modules, parallel buses in accordance with the PCI standard are used. The primary interface between modules is based on the Fibre Channel standard. Both of these standards can be considered as well established and 'state of practice'.
Using PCI as the standard interface of the building blocks allows the building blocks to be exchangeable. For example, a signal processing building block can be exchanged by a data processing building block without major modifications to the rest of the module.
Encapsulating hardware processing elements in that way, using a standard interface, can be considered as a significant step forward to an architecture that is supportive with respect to later obsolescence removal. The building block design becomes transparent to the rest of the module. Hence, changes to the building block driven by obsolescence, even the exchange of a processing chip set, are feasible without major impact on the rest of the module. For example, the signal processing building block currently applies the TI C6701 DSP. Moving to a different Signal Processor type if required due to obsolescence or performance reasons is considered to be possible without affecting the MSU.
Carrying the same idea one step further results in a similar approach when it comes to the application software. Due to the need for high signal processing throughputs, application software in past airborne radars was closely linked with the available hardware resources. Algorithms, requiring fast computation, were reflected in hardware designs, e.g. ASICs and machine code was used as the most effective way of programming with respect to throughput.
However, obsolescence had to be faced, not only the hardware needed to be modified, but also the application software was seriously affected. Since the signal processing software development in military airborne equipment such as a radar can easily exceed one third of the overall development costs, safeguarding this effort is of imminent importance.
With more and more powerful DSPs and PowerPCs becoming available, the emphasis of software development shifts from being effective in terms of throughput towards the need to reduce the software development effort.
Hence, the software for the MSP2 is organised in layers as outlined above, in an attempt to establish standard interfaces. All the different software layers, i.e. board support package, operating system and APOS ensure, that the hardware resources are transparent to the application software. Moreover, APOS ensures, that even the operating system may be exchanged without significant re-work of the application software.
APOS as it was established in the ASAAC programme translates the services provided by an underlying commercial operating system into a standard set of services that can be used by the application software.
Using standard interfaces also makes the use of COTS products possible. In the case of the MSP2, such COTS can be a processing building block, that interfaces with the module via a PMC connector. Application of such COTS modules can be a solution when an early A-Model prototype is required, e.g. to support software development. Using PMC modules in fighter aircraft avionics is currently not envisaged due to the high vibration levels that occur. Other areas of COTS application include the operating system and software libraries.
As it comes to test equipment, the use of standard interfaces offers again an advantage, since readily available COTS test equipment can more easily be used and more expensive STTE avoided, for which obsolete components would be a problem again. Primary test interfaces of the MSP2 are Ethernet, Fibre Channel in conjunction with PC, JTAG and a Fibre channel to VME bus adaptation in order to open the access to a variety VMEbus based test equipment.

As described above, the decreasing component supply voltage level are a primary source for trouble when it comes to obsolescence driven re-designs. As explained in Ref. X, no standard voltage can be foreseen as in the sense the 5.0 volts have been. Solutions to the problem include a dedicated power supply as part of the re-design. However, this need to fit into the power and cooling budget of the obsolete design.
For a new architecture a new approach is suggested. In that the aircraft supplied AC is first converted to DC of some tens of volts in a primary power supply. This is then routed to distributed power supply modules, if the distance between the modules and their total number prohibits direct low voltage delivery. DC/DC voltage level is performed and a standard voltage level is supplied to each module. There are power supply building blocks on each module, that further convert the voltage level to what ever is needed by the components.
In order to be flexible, the power supply building block output voltages are to be programmable in a range of about 1 – 5 volts. Care needs to be taken of the efficiency o such power supply building blocks, as it is likely to increase the dissipated heat of a module significantly.

Design Features that mitigate Obsolescence

Environmental Issues

As outlined above, using commercial or industrial grade components in a military airborne environment, e.g. a fighter aircraft results in a number of environmental issues to be addressed.

The most obvious is the temperature range, the components have to sustain. Regardless of the cooling mechanism, i.e. forced air cooling or convection cooling, the desired high processing power per volume most likely causes high case temperatures. Thermal vias and heat pipes are amongst the known means to mitigate the thermal load of hot components and avoid hot spots.

Another strategy to prevent thermal stress from COTS components is to adopt the available processing power to the needs of the operation where possible. For example, the avionics of a fighter aircraft might be stressed most on the ground, where no conditioned air is available, as the engines are off. In such a situation, most of the avionics equipment may not be required to be fully functional, except for the cyclic self test. Hence, the majority of the processing of the MSP2 can be switched to a ‘sleep’ mode with only a fraction of the normal heat being dissipated.

A more radical approach towards the use of industrial / commercial grade components and boards includes provisions to drastically soften the environmental conditions at all. This may include a ‘hotel room’ environment which protects the components from the environmental extreme. In order to control the thermal conditions, extra heating / cooling equipment needs to be in place. At least in military aerospace applications the system designer is very much confined with power, weight, and volume. Hence, a centralised, high performance environmental control system is needed, which also takes care of humidity. Other features of the hotel room environment include shock absorbers to dampen the mechanical stress from vibrations and shock, and sealed housing, to avoid the penetration of sand, dust, and chemicals.

As the humidity is beside cooling the most critical environmental aspect for PEM components, a lot of effort is put into the development of special coating of critical components or even a complete board. Recently developed coating materials and processes (DaimlerChrysler Research) reduce the diffusion of water to significantly less than 10 % compared with un-coated PEM components.

Providing a hotel room environment might be an option, where it is permitted by the available budgets for primary power, weight, and volume.

There is a temptation to use commercial grade components outside their environmental specifications, as they are from the same die as their military counterparts. However, there is no guarantee, that this will be the case at the next re-design and the equipment designer will be given no notification about any change in the component production process, that could cause the component not to perform at extended temperatures.

Component Selection

Throughout the MSP2 project, care has been taken to what components are to be used. Although commercial grade components have been applied when building functional A Models, the design has been driven by the desire, to minimise the use of commercial components, and rely on manufacturer with an expressed interest in the military market.

QML provides a performance based specification of COTS components that are designed to meet the needs of military applications. Components that fulfil this specification are preferred for various reasons: QML components are more likely to be supported for an extended period of time compared to commercial components, which are driven by the dynamic commercial market. QML manufactures also provide the essential services for an effective obsolescence management, e.g. configuration control and change notifications. QML devices work within a broad temperature range, that allows their application in military aircraft.

The major drawback of going QML is the restricted choice of components. In fact, two of the more significant components used in the MSP2 can be obtained only in a commercial temperature range.

Amongst the options for remedy is an up-screening of commercial components. However, this is thought to be a very risky approach, since it is generally not supported by the original manufacturer, which most likely results in a poor test coverage when it comes to more complex ICs. It will also cause a liability problem if a catastrophic failure happens as the IC manufacturer nowadays protect themselves with disclaimers for their commercial products.

A more elegant approach is the use of FPGAs as a hardware platform that is more flexible and widely available. VHDL as the programming language is well established and will allow a design of the required functionality, that is for the most part independent of the hardware, provided that the FPGA provides the required features / performance. Although, programming the design in VHDL might be initially more expensive, the gained independence from a particular component vendor might be worth the effort, when it comes to obsolescence. Moving from one FPGA to the next generation might only require a limited re-design of the PCB layout and porting the VHDL code. Hence, this approach is not only attractive if no component meets the environmental specification, but also to reduce the life cycle cost in case of obsolescence.

Finally, when a component needs to be selected, it needs to be considered, at what point in its life cycle a component is. It is a mistake to believe, that a component has a low risk of obsolescence, if it is at the beginning of its life cycle. In fact, the risk will be high that a newly introduced device will be removed from the market due to e.g. lack of success. It is much safer, to

choose components, that start to be ‘state of practice’, especially for components that affect the architecture, i.e. interfaces.

Conclusion

System designer for military avionics will be faced with components becoming frequently obsolete. This cannot solely be longer solved by traditional methods including last time buy. Frequent design updates will be part of the future business, requiring a pre-planned product improvement roadmap.
In order to reduce the involved effort, the EADS MSP2 processor development has successfully applied architectural and design measures right from the start of the project. These include a strictly modular software and hardware architecture and the use of ‘state of practice’ standards.
Application of commercial components is seen as being unavoidable, and hence the creation of a moderate thermal and mechanical environment (i.e. ‘hotel room’) will mean a major challenge for the design of future military airborne equipment.
None of the above measures can solve the obsolescence problem on its own, but needs to be embedded in a obsolescence management process.